1 INTRODUCTION

1.1 Background

Facilities licensed by the U.S. Nuclear Regulatory Commission (NRC) are required to demonstrate that residual radioactivity at their site meets the applicable guidelines before the associated license can be terminated. NRC has completed a decommissioning rulemaking effort, that culminated in a *Federal Register* notice on July 21, 1997, to establish residual contamination criteria for release of facilities for restricted or unrestricted use. In support of that rulemaking, the Commission has prepared a Generic Environmental Impact Statement (GEIS), consistent with the National Environmental Policy Act (NEPA).

The effects of this new rulemaking on the overall cost of decommissioning are among the many factors considered in the GEIS. The overall cost includes the costs of decontamination, waste disposal, and radiological surveys to demonstrate compliance with the applicable release criteria. An important factor affecting the costs of such radiological surveys is the minimum detectable concentration (MDC) of field survey instruments in relation to the derived concentration guideline levels (DCGLs)—radionuclide specific levels corresponding to the release criterion. The MDC may apply to either the concentration of radioactivity present on a material surface or within a volume of material. If the DCGLs are lower than the MDC of field survey instruments, extensive laboratory analysis would become necessary, significantly increasing the overall cost of decommissioning projects.

1.2 Need for This Report

Currently, comprehensive and well-controlled data on detection sensitivity of field survey instruments, under conditions typically encountered by licensees during decommissioning, are not available. A literature search was performed on the detection sensitivity capabilities of portable survey instruments. In general, the MDC information contained in the literature is for optimum capabilities under conditions of low background, smooth clean surfaces, and experienced survey personnel. Additional studies were determined to be necessary to develop comprehensive information, relative to instrument performance, under actual field conditions. In the determination of scan MDCs, many studies do not identify the method by which detector sensitivities were determined or defined (e.g., detection sensitivities may be calculated for various confidence levels, using ratemeter output as opposed to integrated counts or audible signal change), and as such, comparison of detection sensitivities reported in the literature may not be appropriate. A few notable studies that do specify the methodology to determine scanning sensitivities are summarized in Section 6.

The purpose of this study was two-fold. First, the results of the study, published herein, will provide guidance to licensees for selection and proper use of portable survey instruments, and an understanding of the field conditions under which, and the extent to which, the capabilities of those instruments can be limited. Second, the data were used to determine the validity of the theoretical MDCs used in the GEIS.

1.3 Scope

The major emphasis of this study was the measure of detection sensitivity for field survey instruments in both the static and scanning modes of operation. The parameters that were studied for their effects on the detection sensitivity of field instruments included variables that determine the instrument MDC (e.g., probe surface area, radionuclide energy, window density thickness, source-to-detector geometry) and variables that can affect the detection sensitivity of the instrument in the field (e.g., various surface types and coatings, including painted, scabbled, or wet surfaces). It was not anticipated that empirical data would be obtained for every possible combination of variables; rather, the emphasis was on establishing the necessary baseline data, so that accurate predictions could be made regarding an instrument's response under a variety of possible field conditions.

Scan MDCs were evaluated for both building surfaces and land areas. The innovative approach used to determine scan MDCs coupled the detector and contamination characteristics with human factors.

The types of instruments commonly used in field radiological surveys that were evaluated in this study included gas proportional, Geiger-Mueller (GM), zinc sulfide (ZnS) scintillation, and sodium iodide (NaI) scintillation detectors. Comparison of field survey instruments by different manufacturers (Ludlum, Eberline, Bicron, etc.) was not the intended purpose of this study. The specific instruments that were used for these measurements are, in general, representative; one notable exception is the pressurized ionization chamber described in Section 2. All instrumentation used in this study is described in Section 2.

The detection sensitivity of a number of commonly used laboratory procedures was also addressed in this study. Because most of the information on laboratory procedures and thermoluminescence dosimeters is already available, this information was provided in the form of a literature review. However, it was anticipated that some laboratory measurements would have to be made to address specific objectives of the study.

Finally, this report was not intended to be a complete evaluation of the performance of portable survey instrumentation. Several references are available that provide comprehensive information on the performance of health physics instrumentation. One such study involves the evaluation of ionization chambers, GM detectors, alpha survey meters, and neutron dose equivalent survey meters according to the draft ANSI standard N42.17 (Swinth & Kenoyer 1984). These instruments were subjected to a broad array of testing, including general characteristics, electronic and mechanical requirements, radiation response, interfering responses, and environmental factors. An important result of the cited study was highlighting the susceptibility of air and gas-flow proportional counters to environmental factors such as humidity, elevations, and temperature. The study also concluded that the alpha scintillation detector is relatively stable under variable environmental conditions. Another study summarized the regulatory requirements and practices of NRC licensees regarding the use of accredited calibration laboratories. That report concluded that more definitive guidance was needed to describe how to perform and document calibration to demonstrate compliance with the regulatory requirements (NUREG/CR-6062).

1.4 Methodology

During radiological surveys in support of decommissioning, field instruments are generally used to scan the surface areas for elevated direct radiation, and to make direct measurements of total surface activity at particular locations. Although the surface scans and direct measurements can be performed with the same instruments, the two procedures have very different MDCs. Scanning can have a much higher MDC than a static count, depending on scanning speed, distance of the probe to the surface, and other instrument factors. The scanning MDC is also affected by the "human factor," described in Section 6. Therefore, when applicable, the MDC of each instrument was determined for both the scanning and static modes of operation.

There are several statistical interpretations of the MDC concept that can result in different MDC values for an instrument, using the same set of data. The specific approach for statistical interpretation of the data, in this study, was selected after a thorough review of the relevant literature. A sensitivity study, evaluating the quantitative effects of various statistical treatments on the MDC, was also performed (Section 3).

Studies were performed primarily at Oak Ridge Institute for Science and Education (ORISE) facilities in Oak Ridge, Tennessee. A measurement hood, constructed of Plexiglas, provided a controlled environment in which to obtain measurements with minimal disturbances from ambient airflow. The Plexiglas measurement hood measured 93 cm in length, 60 cm in height, and 47 cm in depth, and was equipped with a barometer and thermometer to measure ambient pressure and temperature within the chamber. Measurements were performed within the measurement hood using a detector-source jig to ensure that the detector-to-source geometry was reproducible for all parameters studied. Various field conditions were simulated, under well-controlled and reproducible conditions. Special sources were constructed and characterized in ORISE laboratories to meet specific objectives of this study. On the basis of the empirical results obtained from these studies, sets of normalized curves were constructed that would indicate instrument response as a function of source energy, geometry, background radiation level, and other parameters, including source-to-detector distance, window density thickness, and density thickness of overlaying material.

The quantitative data were treated and reported in accordance with Environmental Protection Agency guidance (EPA 1980). Data were reported with an unambiguous statement of the uncertainty. The assessment of the uncertainty included an estimate of the combined overall uncertainty. Random uncertainties associated with measurement parameters (e.g., number of counts, weight, volume) were propagated to determine an overall uncertainty. It was generally assumed that measurement parameters were statistically independent; therefore, the propagation of errors did not consider any covariance terms. Uncertainties were also propagated in the MDC determination to provide a measure of the overall uncertainty in the MDC from both counting errors and other sources of error (e.g., detector efficiency, source efficiency, calibration source activity).

Experts at several other facilities were contacted to discuss various aspects of this study, such as the statistical approaches to MDC measurements, methods for construction of calibration sources, and to obtain calibration sources, already constructed, that could be used in this study. These institutions included the National Institute of Standards and Technology (NIST), the Department

of Energy's Environmental Measurement Laboratory (EML), Argonne National Laboratory (ANL), Pacific Northwest National Laboratory (PNNL), and Oak Ridge National Laboratory (ORNL). ORISE also collaborated with Brookhaven National Laboratory (BNL) to address the "human factor" in performing radiological scan surveys (Section 6).